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QCD CORRECTIONS TO PHOTOPRODUCTION OF W BOSONS AT HERA *

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W bosons can be produced in the channels $e^{\pm}p \to W^{\pm} + X$ at HERA thus allowing anomalous trilinear couplings among the gauge bosons to be probed. We discuss the next-to-leading order (NLO) QCD corrections to the photoproduction of W bosons with finite transverse momentum at HERA. The higher-order QCD corrections reduce the factorization scale dependence significantly and modify the leading-order (LO) cross sections by $\pm\mathcal{O}(10\%)$.

1 Introduction

The study of W bosons at different colliders serves as an important test of the Standard Model and its possible extensions. W bosons can be produced at the ep collider HERA with a center of mass (c.m.) energy $\sqrt{s} \approx 318$ GeV which is achieved by colliding electrons/positrons with energy $E_e = 27.5$ GeV and protons with energy $E_p = 920$ GeV. Since the production cross sections for the processes $e^{\pm}p \to e^{\pm}W + X$ reach values of about 1 pb at HERA, the production mechanisms of W bosons can be studied and the existence of anomalous $WW\gamma$ trilinear couplings can be probed [1, 2]. Moreover, W boson production represents an important SM background to several new physics searches. In particular it is the dominant SM process leading to isolated high energy lepton events with missing transverse momentum [1, 3]. In order to determine potential discrepancies between measurements and Standard Model (SM) predictions, the latter have to be sufficiently accurate and reliable. This is not guaranteed for the available LO calculations of W boson production (see Ref. [4, 5] and references therein). For an unambiguous test of anomalous

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contributions, it is necessary to extend the previous analyses to NLO accuracy. The first step in this direction has been made in Ref. [6], where the QCD corrections to the total resolved photoproduction cross section have been determined. However, the result cannot be used for W boson production with large transverse momentum which is dominated by direct photoproduction. In the following we shall describe the QCD corrections to direct photoproduction which were published in Ref. [5]. The procedure of implementing the QCD corrections in Monte Carlo programs by a reweighting method is described in Ref. [7].

2 Leading Order

W boson production at ep colliders is mediated by photon, Z and W exchange between the electron/positron and the hadronic currents of the process. In general two phase-space regions are distinguished: the deep inelastic (DIS) regime at large Q^2 and the photoproduction regime at small Q^2, Q^2 being the negative square of the transferred momentum from the electron/positron. Details of the calculation of the photoproduction cross section are given in Ref. [5].

The leading direct photon process $\gamma q \to q'W$ develops a singularity at LO when the final state quark q' becomes collinear with the initial state photon. However, the finite transverse momentum p_{TW} of the W boson has to be balanced by the final state quark, so that this singularity does not occur at LO for non-vanishing p_{TW}. The small Q^2 region includes the contribution of the hadronic component of the photon giving rise to $W + jet$ production via $q\bar{q}' \to Wg$ and the crossed processes $gq(\bar{q}) \to Wq'(\bar{q}')$. The treatment of the DIS region is straightforward.

The direct, resolved and DIS contributions add up to the total p_{TW} distribution. Direct photoproduction forms the dominant contribution, while the DIS part is smaller but significant. The resolved component is negligible for $p_{TW} \gtrsim 15$ GeV [8]. The dependence on the specific value of the cut Q^2_{max} which separates the DIS and photoproduction regimes is below the per-cent level [5] and thus sufficiently small.

3 QCD Corrections

For the dominant direct part we have evaluated the NLO QCD corrections. They consist of two parts, the virtual and real corrections. The virtual corrections are built up by all one-loop diagrams which are generated by virtual gluon exchange. They have been computed via dimensional regularization in $n = 4 - 2\epsilon$ dimensions. The quarks have been treated as massless particles.

The real corrections which originate from gluon radiation off the quark lines and the corresponding crossed contributions with the gluon in the initial state have been calculated by means of the massless dipole subtraction method introduced in Ref. [9]. They cancel the infrared and collinear divergences of the virtual corrections and the collinear singularity of the counter term due to the renormalization of the parton densities at NLO, respectively. The NLO parton densities have been defined in the $\overline{\mathrm{MS}}$ scheme. This procedure allows to calculate the real matrix elements in 4 dimensions.

4 Results

We analyzed our final results for direct photoproduction of W bosons plus one jet as well as the inclusive process $W + X$, i.e. without defining jets. Details of the jet requirements, our choice of parton density functions and values of the relevant numerical parameters can be found in Ref. [5].

Setting $\mu_R = \mu_F = M_W$ for the renormalization and factorization scales, we present the final results for the p_{TW} distributions of $W+X$ production in Fig. 1 (a). The QCD corrections modify the direct contribution by about $\pm(10-15)\%$ and are thus of moderate size. To estimate the theoretical uncertainties, the renormalization/factorization scale dependence of the direct contributions to the processes $e^+p \to W^\pm + X$ is presented in Fig. 1 (b) for HERA conditions. The scale dependence is significantly smaller, once the NLO corrections are included. The residual scale dependence is reduced from about 20% down to about 5%. Fig. 1 (b) clearly indicates that the NLO QCD corrections are accidentally small at the central scale determined by the W boson mass. Since the uncertainties of the parton densities are of similar size, the total theoretical uncertainty can be estimated to be less than about 10%.

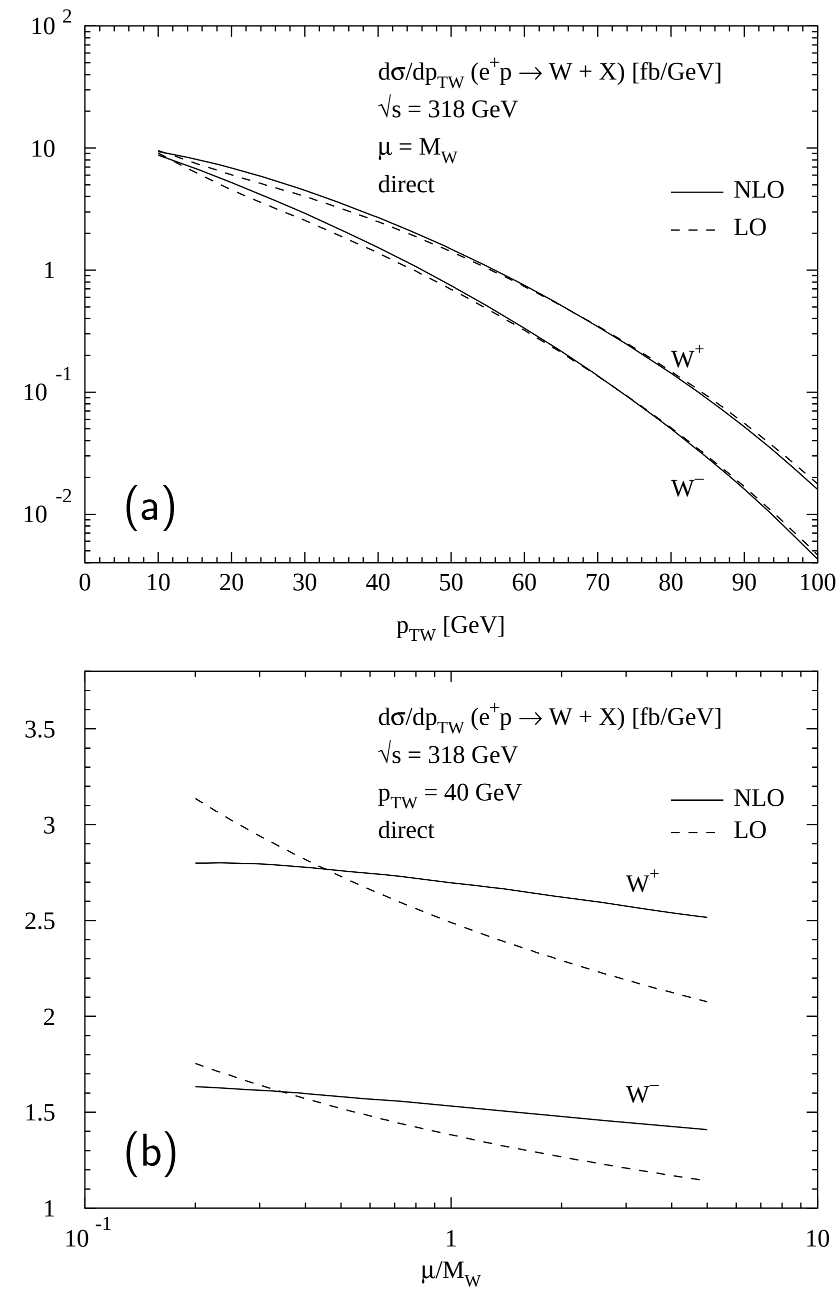

Figure 1: *(a) Transverse momentum distribution of W bosons at HERA for direct photoproduction. (b) Dependence of the direct contribution to W production on the renormalization and factorization scale $\mu = \mu_F = \mu_R = \xi M_W$ for $p_{TW} = 40$ GeV. The full curves represent the NLO and the dashed curves the LO predictions.*

5 Conclusions

We have presented predictions for W boson production at HERA including the QCD corrections to the dominant direct photon mechanism at finite transverse momentum of the W boson. We find that the QCD corrections are of moderate size. However, the QCD corrections to the DIS part are still unknown. They are not expected to be significantly larger, because they have to cancel the Q^2_{max} dependence of the NLO direct contribution and thus have to be of similar size. Since the QCD corrections are dominated by soft gluon effects, the shapes of the differential distributions are hardly affected. Therefore the results obtained in this work cannot explain the excess of isolated high-energy lepton events observed at the H1 experiment [3].

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